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Research report

Attention affects the organization of auditory input associated with the mismatch negativity system

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Abstract

The mismatch negativity (MMN), a component of event-related potentials (ERP), was used to investigate the effect of attention on auditory stream segregation. Subjects were presented with sequences of alternating high and low tones that occurred at a constant rate, which they ignored. When subjects ignored the stimuli, the three-tone standard and deviant sequences contained within the high- and low-pitched tones did not emerge and no MMNs were obtained. Subjects were then instructed to attend to the high-pitched tones of the stimulus sequences and detect the within-stream deviants. When subjects selectively attended the high-pitched tones, MMNs were obtained to the deviants within both the attended and unattended streams. These results indicate that attention can produce segregation such that the sequences of low- and high-pitched tones are available to the automatic deviance detection system that underlies the generation of the MMN. Selective attention can alter the organization of sensory input in the early stages of acoustic processing. © 1998 Elsevier Science B.V.

Keywords: Mismatch negativity; Selective attention; Auditory stream segregation; Event-related potential; Auditory sensory memory

1. Introduction

The mismatch negativity (MMN), a component of event-related potentials (ERPs), indexes early, automatic responses to changes in auditory stimulation, providing information about pre-attentive auditory processing and the representations registered in auditory sensory memory (for reviews, see Refs. [12,17]). The MMN is believed to be the outcome of a comparison process, commonly elicited when an incoming stimulus differs from the memory of repetitive tones (standards) occurring in the recent acoustic past. The differing tones (the deviants) can vary in frequency, intensity, or duration from the standard tones. They can vary along single or multiple acoustic dimensions [8,20,21], by sequential order [19,22,23], or by a change in the abstract representation of pairs of standard tones [16,18]. This pre-attentive comparison process can operate on the spectral, temporal, and spatial information that is stored in the memory that underlies the MMN system. The MMN process is considered pre-attentive because attention is not required to produce it. For instance, MMNs were obtained in the above-mentioned studies while the subjects ignored the stimuli (e.g., reading a book).

The MMN is a negative wave, which is maximal over the fronto-central regions of the scalp and varies in latency in relation to the difficulty or timing of the discrimination between the standard and the deviant. The latency of the MMN increases as the discrimination gets more difficult. The amplitude of the MMN increases as the discrimination gets easier.

1.1. MMN and attention

Mäntasylo and Näätänen [9] and Näätänen [11,12] originally proposed that the amplitude of the MMN is largely insensitive to manipulations of attention (see also [3]). Woldorff et al. [24] were the first to show an attentional effect on the MMN system for intensity deviants. In a follow-up study using the Woldorff et al. [24] paradigm, Näätänen et al. [13] presented subjects with high frequency tones in one ear and low frequency tones in the other. Subjects were asked to attend to one ear and count the number of designated difficult-to-detect deviants (either frequency or intensity) occurring in that ear. Another condition used the same demanding dichotic paradigm,

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except subjects were asked to ignore the stimuli. The amplitudes obtained for the frequency-deviant MMNs were similar for the attended and unattended stimuli, as well as for the ignored stimuli. Therefore, the MMN process for frequency-deviants was unaffected by the direction of attention. The amplitude of the MMN elicited by the deviants that differed from the standards in intensity, on the other hand, were affected by manipulations of attention. When attention was strongly focused toward one ear (necessitated by the demand of the task), the intensity-deviant MMN was significantly reduced in amplitude for the responses obtained from the unattended ear. However, an MMN was obtained to the intensity-deviants when subjects ignored the stimuli altogether with an amplitude that was not significantly different than the amplitude of the intensity-deviant MMN obtained for the attended channel. Thus, it appears that when a high degree of attention is required in one direction, the amplitude of the MMN is reduced for intensity changes occurring for the unattended stimuli.

Alain and Woods [1] also demonstrated that attention can modulate the amplitude of the MMN. They presented two alternating high tones of different frequencies to one ear and two alternating low tones of different frequencies to the other, with breaks (by repetition) in the alternation constituting a deviant. Deviants occurred within the tones presented to both the attended and unattended ears. In another condition, ERPs were collected while subjects ignored the stimuli. The results were similar to the results of the Näätänen et al. [13] study with regard to intensity deviants. The amplitude of the MMNs obtained for the unattended channel were considerably smaller than those obtained in the attended channel, whereas the MMNs obtained during the ignore condition were not.

Attention can modulate the MMN component in an additional way: by inducing it or increasing its amplitude [7,14]. In a study by Näätänen et al. [14], standard stimuli were composed of eight 50-ms segments that each differed in frequency (creating one standard stimulus 400 ms in duration). The sixth segment of the deviant was higher in frequency relative to the sixth segment of the standard. The study was presented in three ignore phases and two active discrimination phases. Discrimination phases occurred after the first and second ignore phases, in which subjects were asked to press a key every time they heard a deviant stimulus. The results were divided into three types of behavioral responses. 'Non-improvers' refers to those subjects whose performance (detecting the deviant sixth segment of the stimuli) did not improve across the two discrimination phases. No MMNs were obtained in any of the ignore phases for these subjects. 'Improvers' refers to those subjects whose performance was not good in the first discrimination phase yet improved in the second discrimination phase. In this group, no MMN was obtained in the first phase, was obtained in the second ignore phase, and increased in amplitude in the third ignore phase. 'Good non-improvers' refers to those subjects whose performance was good in the first discrimination phase and remained good in the second discrimination phase. In this group, MMNs were obtained in the first ignore phase and the amplitude remained similar throughout all ignore phases, whereas the latency of the MMN decreased from the first to the third ignore phase. A second experiment was conducted with no active discrimination phases to determine whether the increased exposure to the stimuli by itself could effect similar results. The MMNs exhibited no significant amplitude changes across the three phases. The authors concluded that attention directed to the stimuli made the representation of the standard more accurate. Thus, attention to the stimuli presumably produced an increased ability to automatically detect the deviation in the complex stimuli, as manifested by an increase in amplitude or decrease in latency of the MMN.

In the study of Näätänen et al. [13], the MMN elicited by the intensity deviants in the unattended channel was reduced, or abolished. It may be reasoned from this that the modulation was the result of an attenuation of the system that generates the MMN. That is, the information about the changes in loudness level were represented (i.e., all incoming information was analyzed at least at the feature level) but that the withdrawal of attention affected the amplification system of the MMN process to a degree in which the amplitude was reduced [13]. Or, it could be reasoned that the modulation was a result of an early gating process, such that the representation of loudness was not distinctive enough for the brain to detect changes in the loudness level occurring in the unattended channel [24]. By contrast, in the study of Näätänen et al. [14], directed attention to the stimuli was postulated by the authors to result in a more accurate representation of the standard stimuli, such that when subjects subsequently ignored the stimuli there was an increase in the amplitude and decrease in the latency of the MMN in a sub-group of the subjects. Collectively, the results of these studies indicate that attention can affect the amplitude and latency of the MMN.

The purpose of the present study was to determine whether focusing attention on a subset of concurrent stimuli could alter the manner in which the brain organizes the processing of the stimuli such that an MMN would be produced.

Auditory scene analysis [4] is a term used to describe a process by which the auditory system decomposes the mixture of sounds arriving at the ears into meaningful segments or groupings. Thus, the task of the brain is to disentangle the mixture of sounds to their original sources, keeping them distinct. Cues for this sorting process can be provided by similarities in the properties of the acoustic energy, such as the frequency range of the sounds, their spatial location, intensity, or rate at which the sounds occur. The sequential integration of tones may occur on the basis of *shared* properties, whereas the segregation of tones may occur on the basis of *contrasted* properties.

Whether the sound is sequentially integrated, or separated into distinct sound sources, is influenced by the context of the adjacent sounds. For example, if a sequence of tones alternates across high and low frequency ranges at a rapid pace, the perception of the sequence splits into two separate sound sources, one made up of the high tones and one of the low (the streaming effect; Ref. [4]). If the same sequence occurs at a slow pace, alternating high and low pitches are perceived. The grouping, in this case, would depend on the rate at which the tones occur, as well as the frequency separation between them. Whether they are processed as one or two streams is dependent upon the context within which the stimuli occur.

Sussman et al. [23] found that alternating high and low tones segregated into two streams pre-attentively when occurring at 100 ms intervals but not at 750 ms intervals, when subjects ignored the stimuli. When the tones were presented at the fast pace, an MMN was obtained by the deviant sequences occurring within both the high- and the low-tone streams. Since subjects ignored the stimuli, the presence of the MMN during the streaming effect indicated that the segregation of the tones occurred automatically, at or before the level of the MMN system. On the other hand, when tones were presented at a slow pace, no MMNs were obtained for either the high or low tones. Thus, the alternation of the high and low tones interfered with the emergence of the within-stream sequences. Segregation did not occur automatically at the slow pace, yet did occur automatically at the fast pace. These results led us to ask whether attention to either the high or low tones presented at a slow pace could produce segregation, thereby altering the processing of the stimuli at a pre-attentive level, and generating an MMN.

Accordingly, in the present study, sequences of alternating high and low tones (as described above) were presented in attend and ignore conditions at a slow stimulus rate which was not expected to produce streaming automatically, to investigate whether the MMN would indicate differential processing as a function of attention. The rate of alternation between the high and low tones was held constant across both conditions, while the state of attention was varied. We speculated that when subjects ignored the stimuli, no MMNs would be elicited by the within-stream deviant sequences, whereas with attention focused on a subset of the tones, MMNs would be elicited by the within-stream deviant sequences.

2. Materials and methods

2.1. Subjects

Eleven subjects (eight females) between the ages of 24 and 43 years, with reportedly normal hearing, were paid for their participation in the experiment. Three subjects were dropped from the study because they were unable to perform the task during the attention phase of the study.

2.2. Experimental procedure

Subjects were seated in a comfortable chair. The stimuli were six pure tones (400 Hz, 450 Hz, 500 Hz, 1150 Hz, 1250 Hz, and 1350 Hz) presented binaurally through insert earphones. Each tone was 50 ms in duration, including a 7.5 ms rise/fall time, with an intensity of 75 dB SPL.

High (1150 Hz and above) and low (500 Hz and below) frequency tones were alternated at a constant SOA of 500 ms. A rising sequence of the three high frequency tones and a rising sequence of the three low frequency tones were alternated (e.g., L1, H1, L2, H2, L3, H3; where L1 equals 400 Hz and H1 equals 1150 Hz). This six-tone cycle constituted the standards and occurred on 87% of the trials. A deviant (falling) three-tone sequence (e.g., L3, L2, L1) occurred on 13% of the trials, half within the low tones and half within the high tones. The deviants (25 per run for the low tones and 25 per run for the high tones) occurred randomly within the fourteen runs created for the study. All of the runs were randomized to ensure that

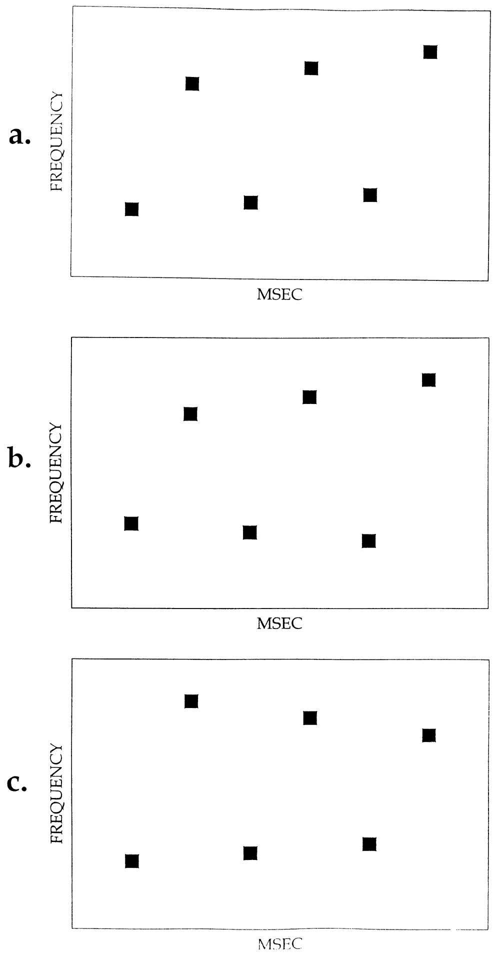

Fig. 1. Example of a standard cycle of six tones (a), a deviant occurring in the low tones (b), and a deviant occurring in the high tones (c).

sequences were not predictable when subjects attended to the tones. Seven runs each were used for the ignore and attend condition, and the order of the runs was counterbalanced across subjects. The standard and deviant sequences are presented in Fig. 1.

There were two parts of the study. In the first part, subjects were instructed to ignore the stimuli by reading a book of their choice (ignore condition). Since it was necessary to determine that no MMN would be elicited in the ignore condition, it was run first for all subjects. Subjects then took a break as long as needed.

In the second part of the study, subjects were instructed to attend to the high tones and ignore the low tones, pressing a key every time they heard a deviant high-tone sequence (attend condition). A practice session was given in two phases. In the first phase, the high tone sequence was presented alone at the rate of stimulation the high tones occurred in the alternating sequence (1 tone per second). Subjects were instructed to listen for a three-tone rising standard sequence and tell when they heard a three-tone falling deviant sequence. When it was clear that the subjects could hear the standards and deviants within the high tones sequence, the second phase was conducted. In the second phase of the practice session, an alternating sequence of high and low tones similar to that to be used during the recording session was presented. Subjects were now instructed to pay attention to the high tones only while ignoring the low tones, and to press the keypad every time they heard the deviant (falling) high-tone sequence. When subjects understood what to do and could perform the task, recording proceeded. Short breaks were given as needed after each run.

2.3. ERP recording

The electrical brain activity was recorded using direct-coupled (DC) amplifiers, with a low-pass filter setting of 40 Hz, and a digitization rate of 500 Hz. The epoch duration was 600 ms. A 500 ms poststimulus epoch was used along with a 100 ms prestimulus baseline. Recordings were obtained at the following electrode sites: Fpz, Fz, Cz, Pz, Oz, Fp1, Fp2, F3, F4, F7, F8, FC5, FC6, FC1, FC2, T3, T4, C3, C4, CP5, CP6, CP1, CP2, T5, T6, P3, P4, O1, O2, LM, and RM (left and right mastoids, respectively). The nose was used as a reference. Horizontal eye movements were monitored using electrodes F7 and F8. Vertical eye movements were monitored with a bipolar electrode configuration using Fp1 and an external electrode placed below the left eye. Artifact rejection was set to automatically reject activity exceeding ±100 μV. The averaged

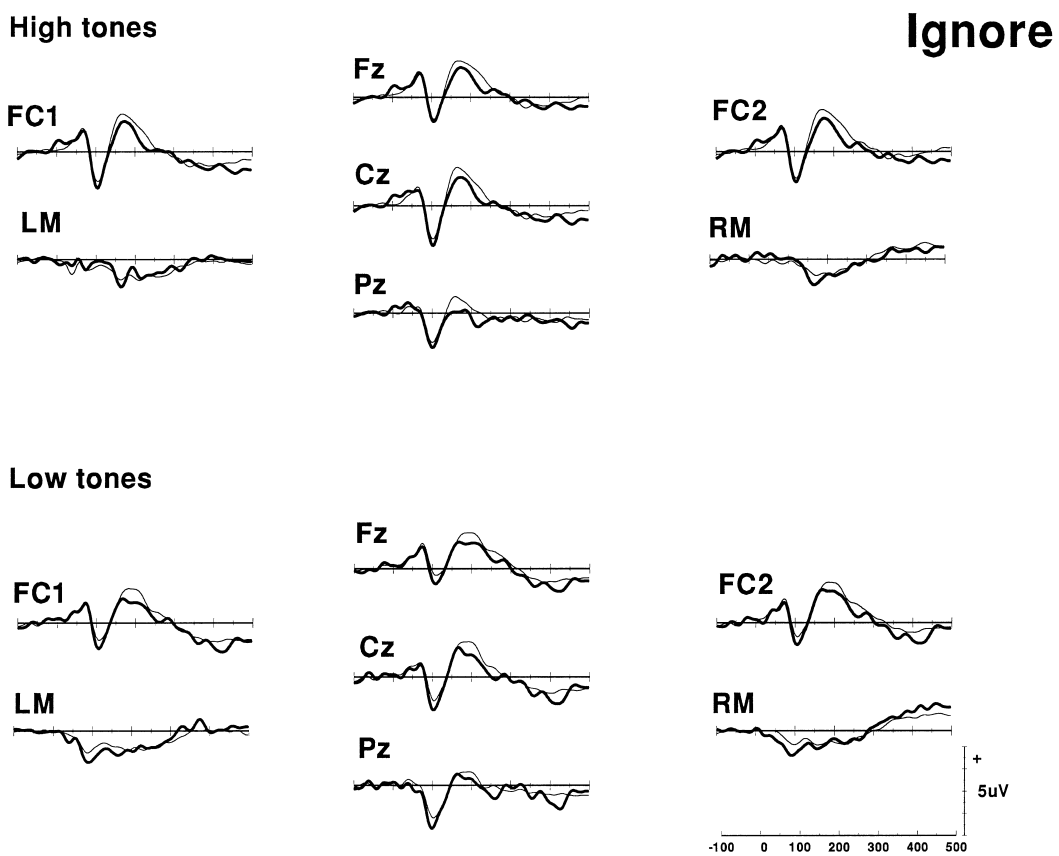

Fig. 2. Ignore condition grand averaged standard (thin line) and deviant (thick line) waveforms obtained for the high tones (top) and the low tones (bottom) separately at Fz, Cz, Pz, FC1, FC2, LM, and RM.

ERPs remaining were examined for residual artifact. ERPs were digitally filtered off-line with a bandpass of 1–30 Hz.

2.4. Data analysis

In Sussman et al. [23], the MMN was elicited by the first tone of the three-tone deviant sequence. On this basis, these data were similarly analyzed. ERPs elicited by the first tone of each standard sequence were averaged together across the runs for each subject, separately for the high and low tones, in each condition. Likewise, the ERPs elicited by the first tone of the deviant sequence were averaged together across the runs, separately for each subject, each set of tones, in each condition.

The grand mean ERPs were used for the purposes of display. Grand mean difference waveforms were calculated by subtracting the ERPs elicited by the standard from those elicited by the deviant, separately for each set of high and low tones and each condition. The peak latency of the MMN was selected at Fz in the grand mean difference waveforms as 237 ms for the unattended tones in the attend condition. The amplitude of the ERPs elicited by the standards and deviants for each subject in each condition were measured at Fz in a latency window from 25 ms before to 25 ms after the peak latency of the MMN in the grand mean difference waveforms.

The data were statistically analyzed using a two-way analysis of variance (ANOVA) for repeated measures with factors of stimulus type (standard and deviant) and electrode (Fz, Cz, FC1, FC2, LM, and RM) to determine whether the ERPs associated with the standard were significantly different than the ERPs associated with the deviant in the latency range of the MMN. Tukey post-hoc comparisons were then used to determine statistical significance at individual electrode sites. Since there was no evidence of an MMN for either the high or the low tones in the ignore condition, the mean voltages, in the 50 ms window taken around the peak of the MMN of the unattended stream in the attend condition were used to determine whether the ERPs to the standard and deviant differed significantly at Fz, Cz, FC1, FC2, LM, and RM in the ignore condition.

To compare differences in scalp distributions between the ERPs obtained for the unattended stream with the ERPs obtained by the attended stream in the attend condition, mean voltages were measured around the peak negativity in each stream separately. Peak latency was chosen as 213 ms for the attended channel and 263 ms for the unattended channel. The data were scaled [10] and then evaluated using the factors of channel (attended–unattended) and electrode (all 32 recording sites were included in the analysis) in a two-way repeated measures ANOVA.

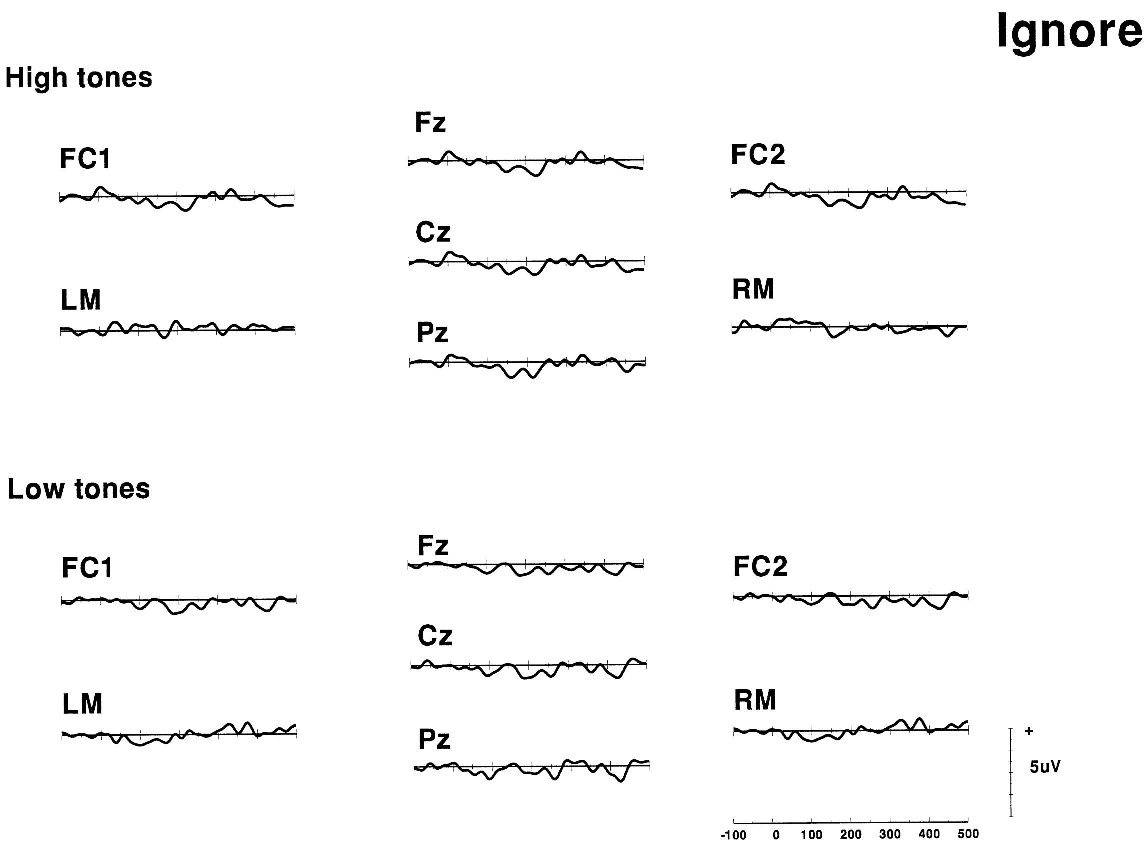

Fig. 3. Ignore condition grand averaged difference waveforms (deviant minus standard ERPs) obtained for the high tones (top) and the low tones (bottom) separately at Fz, Cz, Pz, FC1, FC2, LM, and RM.

An alpha level of 0.05 was used. Huynh–Feldt corrections were reported when appropriate.

3. Results

3.1. Subject report

At the end of the ignore phase, subjects were asked how they heard the tones, if they noticed. Subjects reported that when they noticed they heard alternating high and low pitches. At the end of the practice phase, subjects were asked if they noticed the three-tone sequences during the ignore phase. No subjects noticed, and were surprised when told that the tones they were now attending were the same type sequences as the tones they had been ignoring. All subjects reported that they could segregate the high from the low tones, and that it took some time at the start of each run to segregate the tones. The task, finding the high tones deviant within the three-tone standards, varied in difficulty level from subject to subject. However, all subjects reported that highly focused attention on the high tones was required to complete the task on each run of the session. That is, undivided attention was necessary to keep track of the standard three-tone pattern within the high tones.

3.2. Ignore condition

Fig. 2 displays the group averaged standard and deviant ERPs obtained separately for the high (top) and low (bottom) tones at Fz, Cz, Pz, FC1, FC2, LM and RM. The typical N1–P2 components elicited by the standards can be clearly seen, with peak latencies for the high tones of 106 ms (N1) and 170 ms (P2), and for the low tones of 108 ms (N1) and 190 ms (P2). The N1 amplitude, measured at Fz, was larger for the high tones than for the low tones ($t = 3.54$ [7 df]; $p < 0.01$). The difference waves, obtained at the same electrodes, are displayed in Fig. 3. Some small negativities are present in the waves for both the high and the low tones. However, there was no significant difference between the standard and deviant ERPs for either the low tones (F [1, 7] $= 1.3$, $p = 0.29$) or the high tones (F [1, 7] $= 2.0$, $p = 0.26$). Thus, no MMNs appear to have been elicited when subjects ignored the stimuli.

3.3. Attend condition

Fig. 4 displays the group averaged standard and deviant ERPs obtained separately for the attended (top) and unat-

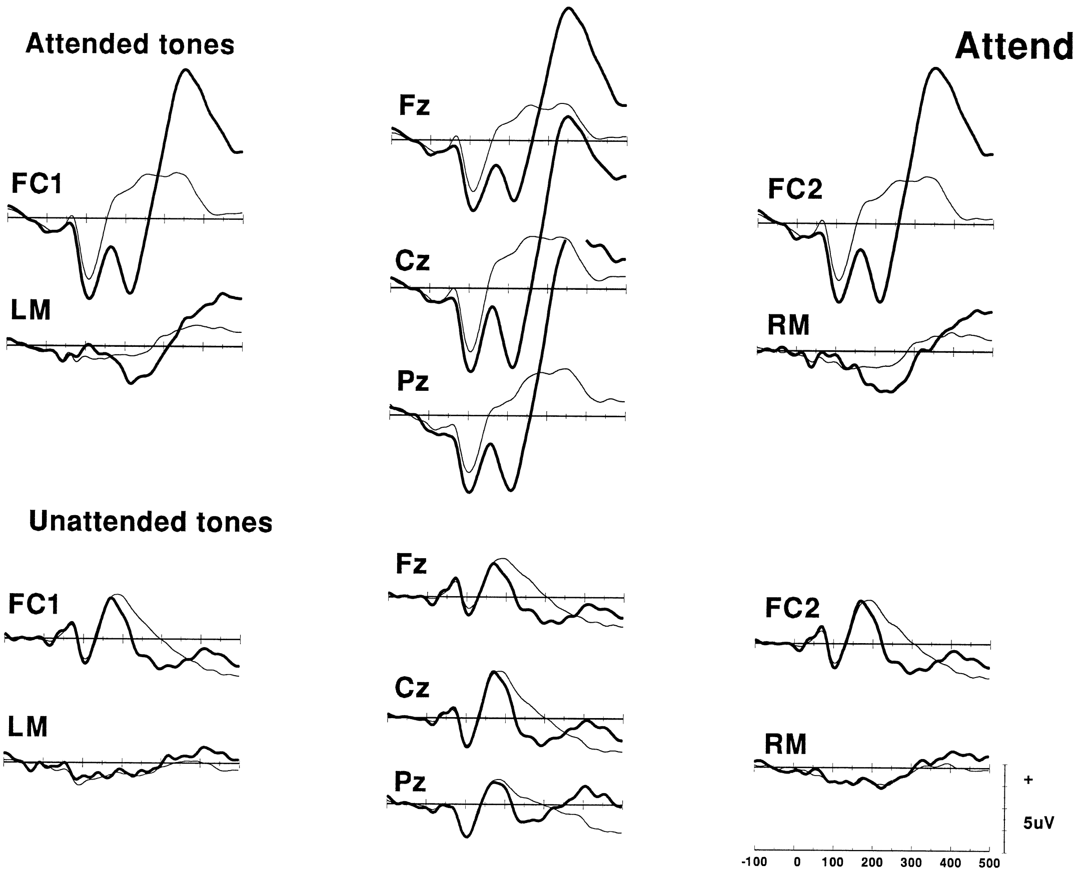

Fig. 4. Attend condition grand averaged standard (thin line) and deviant (thick line) waveforms obtained for the high tones (top) and the low tones (bottom) separately at Fz, Cz, Pz, FC1, FC2, LM, and RM.

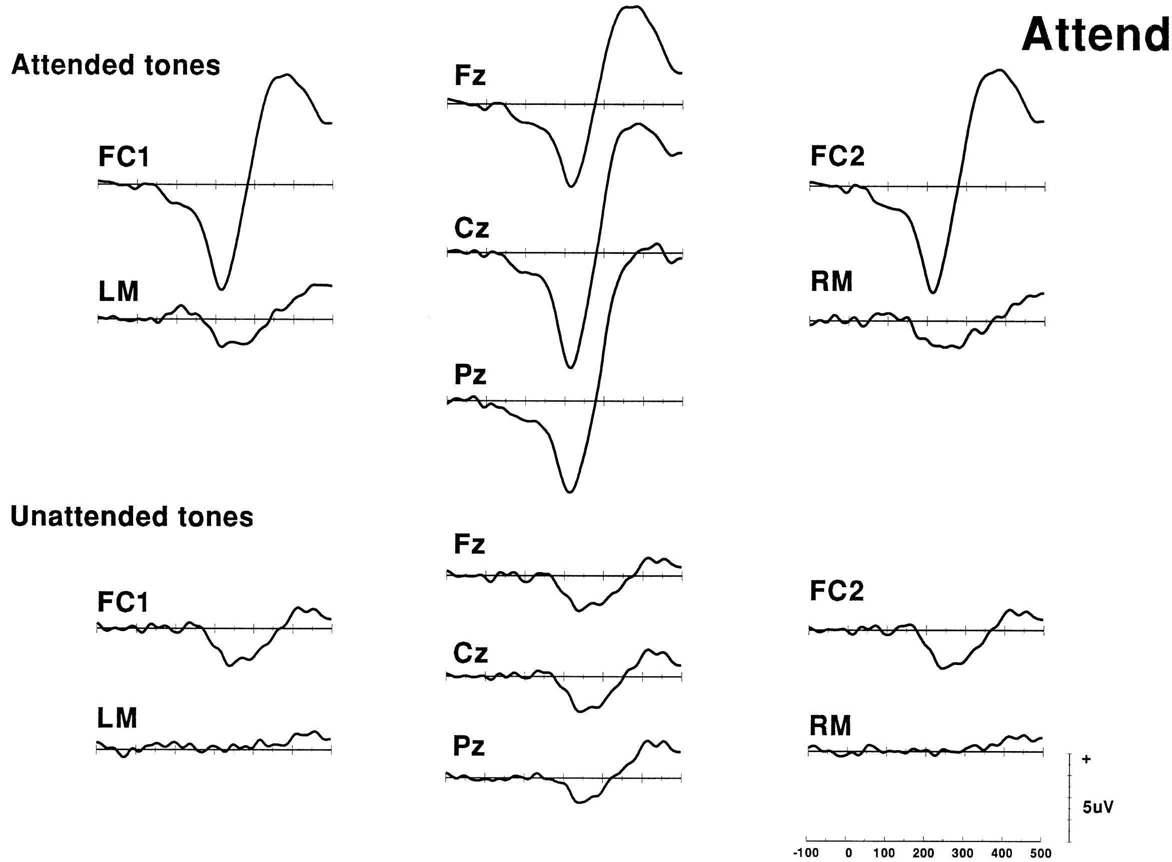

Fig. 5. Attend condition grand averaged difference waveforms (deviant minus standard ERPs) obtained for the attended tones (top) and the unattended tones (bottom) separately at Fz, Cz, Pz, FC1, FC2, LM, and RM.

tended (bottom) tones at Fz, Cz, Pz, FC1, FC2, LM and RM. The N1–P2 components elicited by the unattended tones can be seen in the standard and deviant waveforms. A broad negative deflection, denoting the MMN, follows the N1–P2 components in the deviant waveforms. The ERPs elicited by the standard attended tones exhibit an N1 and P2 followed by a late positivity displaying two peaks. In the deviant waveforms, N1 and P2 are followed by another negative deflection and a large positive deflection (P3), peaking at about 360 ms. N1 amplitude, measured at Fz, was larger for the attended tones than for the unattended tones ($t = 8.99$ [7 df]; $p < 0.001$). Notice that the P3 component, associated with conscious target detection, is present in the deviant waveforms elicited by the attended tones but not the unattended tones.

Table 1
Amplitude in μV (and standard deviation) of the standard and deviant ERPs and the difference waveform measured on the grand means in the latency window of the MMN for the unattended tones in the attend condition

Electrode	Standard	Deviant	Difference	p^{**}
Fz	1.37 (0.8)	−0.41 (1.5)	−1.78	
Cz	1.26 (0.9)	−0.48 (1.4)	−1.74	**
FC1	1.31 (0.9)	−0.54 (1.6)	−1.86	**
FC2	1.38 (0.7)	−0.55 (1.5)	−1.93	**
LM	−0.68 (0.5)	−0.59 (1.2)	−0.09	
RM	−0.85 (0.5)	−0.95 (0.9)	0.10	

** < 0.01.

Fig. 5 displays the difference waves obtained by subtracting the ERPs for the standards from those for the deviants in each condition. In the attended condition, MMNs were elicited by the deviants in the unattended stream (F [1, 7] = 14.06, $p < 0.01$). Tukey HSD post-hoc comparisons resulted in significance at the frontal electrode sites but not at the mastoid sites. No significant reversal in polarity was obtained. Table 1 presents the grand mean amplitudes of the standard and deviant ERPs measured in the latency range of the MMN. The peak amplitudes of the MMN component obtained in the same latency window are also provided. The positive-going waves that can be seen in the unattended difference waves at the midline and FC1 and FC2 are caused by the standard ERPs going more negative than the deviant ERPs at the end of the epoch (see in the unsubtracted waveforms in Fig. 4). The MMN elicited by the unattended tones indicates that segregation was brought about by attention.

A significant interaction was obtained on the scaled data indicating a difference in the scalp topography obtained in the region of the peak negativity by the ERPs in the attended and the unattended streams (F [1, 31] = 3.75,

$p = 0.03$). A post-hoc investigation of the electrode sites by scalp region indicated that the frontal, central, and temporal recording sites were contributing to this difference.

4. Discussion

The results of this study demonstrate that selective attention can alter the organization of sensory input. Attention to a subset of sequentially patterned tones can induce segregation so that automatic detection of the deviant sequences is initiated. This was contrasted with the results obtained when subjects ignored the stimuli and no MMNs were elicited. The brain can organize acoustic information differently when selectively attending than when ignoring.

The MMN obtained in the unattended stream indicates that the input to sensory memory was altered (compared to the ignore condition) as a function of attention. There is a relationship between the pre-attentive processes associated with generation of the MMN component and the attentional mechanisms enlisted for segregating the high from the low tones. How pre-attentive and attentive mechanisms can operate simultaneously can be seen in the well-known example of the cocktail party phenomenon. During a cocktail party, the listener can decide which voice, or conversation, to listen to while ignoring the rest of the ongoing party noise. The cues which help the listener distinguish one conversation from the others, such as the location from which the voice is coming from or the pitch and loudness of the voice, are usually processed pre-attentively. That is, we listen to the content of the speaker's message without mixing up the acoustic characteristics of the speaker's voice with other voices in the room. This is an example of how an attentional process (i.e., the decision to listen to a particular voice) can influence a pre-attentive process (i.e., the subsequent selection by the brain of the ongoing target conversation).

This study supports the notion that both pre-attentive and attentive mechanisms play a role in auditory stream segregation. Bregman [4] distinguishes between primitive and schema-driven processes that govern stream segregation. Segregation that is based on primitive processing occurs outside the focus of attention and is determined by stimulus characteristics. The streaming effect that is induced by rapid alternation of high and low tones is an example of stream segregation elicited through primitive processing [23]. Schema-driven processes, on the other hand, rely on attention (and/or past knowledge). A study by Dowling [6] is an example of schema-driven stream segregation. He overlapped a familiar melody with a background melody of the same frequency range. Subjects could not hear the familiar melody without instruction to listen for it, most likely due to the interference of the melodies with one another because they occurred within the same range. Subjects easily heard the familiar melody when instructed to listen for the familiar melody prior to presentation of the overlapped melodies. Dowling [6] concluded that prior instruction provided a schema that guided identification of the target melody. In other words, the segregation of the two melodies occurred as a function of schema-driven attention since the melody was not noticed when subjects attended the combined melodies without instruction.

The relationship between the primitive processes and schema-driven processes can be seen in the ERPs. In Sussman et al. [23], when subjects ignored sequences of high and low tones similar to those used in this study, streaming, as evidenced by the MMN obtained to the deviant sequences within each stream, occurred at a fast but not at a slow rate of stimulation. The streaming effect occurred without attention and, therefore, is considered to depend upon a primitive process. In the current study, the relatively slow stimulus rate used did not induce segregation of the high and low tones automatically, and no MMNs were obtained when subjects ignored the stimuli. When active attention led to perception of the three-tone sequence in the attended stream, MMNs were elicited to the deviant sequence in the unattended stream. The presence of MMNs to the deviant sequences in the unattended channel indicates that schema-driven processes can alter the organization of the sensory input, thereby producing a discriminative effect comparable to that occurring with streaming induced by 'primitive' processes. These findings suggest that it will be fruitful to examine physiological similarities and differences between the primitive and schema-driven mechanisms of auditory stream segregation.

Although this study was not designed to directly compare the physiological processes that occurred in the attended and unattended channels, difference in these processes can be clearly seen in Figs. 4 and 5. The P3 component appears when subjects attend deviant (or target) stimuli, and generally does not appear when subjects ignore or do not attend the stimuli (see Ref. [5] for a review). Compare, in Fig. 4, the ERPs elicited by the deviant attended tones (top) with the ERPs elicited by the deviant unattended tones (bottom). A clear P3 component, occurring at about 350 ms and maximal at Pz, can be seen in the deviant waveforms for the attended tones, but not so for the unattended tones. This indicates that subjects were selectively attending the high tones [1]. The findings in the

[1] One way to determine whether subjects selectively attend stimuli is by examining an endogenous component that is associated with selective attention called the processing negativity (PN) or the negative difference wave (Nd). The component can be delineated by subtracting the standard ERPs obtained for the unattended channel from the standard ERPs obtained from the attended channel. In the current study, a processing negativity was not observed. Since the attended and unattended tones were alternated, they were predictable. Consequently, differences that might be seen between the attended and unattended standard ERPs would be difficult to evaluate since they could be due to differential arousal associated with attended and unattended stimuli.

attended channel are generally consistent with earlier studies and have been examined in detail elsewhere [2,12,13,15]. What is important for the present study is the clear presence of MMN in the unattended channel, with the absence of any of the ERP features that characterize active discrimination.

We can conclude that the discriminative effect indexed by the MMN in the unattended channel represents an automatic process operating on the stimulus pattern contained in the low-pitched tone sequence. The segregation of high- and low-pitched tones that supports this automatic discrimination is obviously dependent upon the active segregation of the high-pitched tones mediated by attention to them. However, this attentional segregation permits the operation of an apparently independent automatic mechanism mediated by the MMN system. In other words, the attentional effect appears manifest in the unattended channel as a consequence of the reorganization of the sensory input. The exact locus and time course of this restructuring of the sensory stream organization remains to be determined.

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